PERFORMANCE OF ADVERA® WARM MIX ASPHALT WITH RECLAIMED ASPHALT PAVEMENT MATERIALS

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PERPUSTAKAAN TUNKU TUN AMINAH

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Alhamdulillah, praise to Allah for giving me the strength and opportunity to complete this study.

I dedicate this thesis to my beloved wife, Hazirah Binti Bujang and my lovely daughter, Adra Irdina Binti Mohammad Nasir and Adni Safiya Binti Mohammad Nasir for their love and sacrifice.

To my beloved parents and siblings : Mohamad Taher Bin Saleh and Rajiah Binti Adnan, Ediwarman and Misnar. Thank you for your prayers and support, and for always being there for me through happiness and sadness.

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Everybody have a dream,
When you lose your dream..You die
There are so many people walking around
Who are dead and they even know it..-MNT-

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ABSTRACT

The rising of energy consumption and poor air quality issues have raised global attention and implementation of warm mix asphalt (WMA) technology in the asphalt industries. The constant efforts by asphalt industry to reduce emissions by lowering asphalt production temperature, made possible by incorporating warm asphalt additive named Advera®. Reclaimed asphalt pavement (RAP) and warm mix asphalt (WMA) have become the alternative materials and methods for enhancing sustainability in the asphalt industry. This study aims to determine the optimal warm mix additive and RAP through several laboratories tests. Binders blended with 0, 4, 5, 6 and 7% Advera® were evaluated using the Superpave ™ rotational viscosity and dynamic shear rheometer to investigate rheological characteristics after being conditioned in a rolling thin film oven. In this respect, conventional asphalt binder grade PG64 was used as the base binder. Performance of modified samples incorporating 10, 20, 30 and 40% RAP of total mass were evaluated for resilient modulus, rutting and moisture susceptibility. The results show that Advera®. modified binder significantly reduced mixing and compaction temperatures. Modified binder with 5% Advera® show significant increase in rutting resistance for both unaged and short term aged compared to virgin binder. The microstructure of Advera® modified asphalt binder also changed significantly compared to the control asphalt. The morphological evaluation shows that Advera® modifier was completely blended with the binder. The performance of 40% RAP modified WMA mixtures produced at 30^{o}C lower than conventional HMA show increases 20-35% on performance in term of resilient modulus (M_R), rutting and moisture susceptibility. Statistical analysis on correlation between rheological Advera® modifed binder and performance of RAP modified WMA mixture proved that there is a strong correlation exists between viscosity and rutting properties. Thus, the combination of Advera® and reclaimed asphalt pavement (RAP) offer alternative way to reduce the high temperature mix, consequently slow the aging of the modified mixture without compromising its performance.

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ABSTRAK

Peningkatan kadar penggunaan tenaga dan tahap kualiti udara yang rendah telah menarik perhatian global untuk menggunakan teknologi campuran asfalt bersuhu rendah dalam industri asfalt. Usaha berterusan bagi mengurangkan pencemaran dengan merendahkan penghasilan suhu campuran asfalt, dengan bahan tambah asfalt suhu rendah yang dikenali sebagai Advera®. Kombinasi pengunaan asfalt tebusguna *(RAP)* dalam campuran asfalt bersuhu rendah *(WMA)* merupakan bahan dan kaedah alternatif dalam meningkatkan industri asfalt yang mapan. Kajian ini dijalankan bagi menentukan kandungan optima campuran bahan tambah dan asfalt tebusguna *(RAP)* melalui siri ujikaji makmal. Bitumen terubahsuai mengandungi 0, 4, 5, 6 dan 7% bahan tambah Advera® dianalisa menggunakan ujikaji berdasarkan piawaian Superpave ™ melalui ujian kelikatan putaran dan reometer ricih dinamik untuk mengkaji sifat-sifat reologi selepas dikondisikan di oven putaran filem nipis. Oleh itu, bitumen konvensional PG64 digunakan sebagai bitumen kawalan. Prestasi sampel terubahsuai mengandungi 10, 20, 30 dan 40% *RAP* dari jumlah berat spesimen dinilai terhadap modulus keanjalan, perpaluhan dan rintangan kelembapan. Keputusan menunjukkan bahawa bitumen terubahsuai dengan Advera® mengurangkan suhu pencampuran dan pemadatan. Bitumen terubahsuai dengan 5% Advera® secara signifikan meningkatkan rintangan perpaluhan pada kedua-dua, tanpa penuaan dan penuaan jangka pendek. Mikrostruktur bitumen terubahsuai dengan Advera® juga turut signifikasi berubah dengan penilaian morfologi menunjukkan bahan tambah Advera® bercampur seragam dalam bitumen. Prestasi sampel terubahsuai mengandungi 40% *RAP* membuktikan bahawa campuran WMA yang dihasilkan pada suhu 30^{o}C lebih rendah daripada campuran konvensional HMA menunjukkan peningkatan sekitar 20-35% ke atas prestasi dari sudut modulus kekukuhan (M_R), perpaluhan dan rintangan kelembapan. Selanjutnya, analisa statistik ke atas korelasi diantara sifat reologi bitumen terubahsuai dengan kejuruteraan campuran WMA mengandungi RAP membuktikan wujud hubungan kukuh antara kelikatan dan ciri perpaluhan. Oleh itu, kombinasi penggunaan Advera® dan asfalt tebusguna (*RAP*) adalah pilihan alternatif dalam mengurangkan suhu campuran asfalt dan memperlahankan proses penuaan campuran terubahsuai tanpa mengurangkan prestasi campuran asfalt.

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LIST OF SYMBOLS AND ABBREVIATIONS

ε	-	Accumulated micro strain
μ	-	Poisson's ratio
δ	-	Phase Angle
AASHTO	-	American Association of State Highway and Transportation Officials
ACWC	-	Asphalt Cement Wearing Course
ANOVA	-	One-way Analysis of Variance
AR	-	Area Ratio
ASTM	-	American Society for Testing and Materials
BBR	-	Bending Beam Rheometer
DP	-	Dust Proportions
DSR	-	Dynamic Shear Rheometer
DTT	-	Direct Tension Test
EPA	-	Environmental Protection Agency
FRAP	-	Fractionated Reclaimed Asphalt Pavement
FTIR	-	Fourier transform infrared
G_{mm}	-	Maximum theoretical specific gravity
G_{mb}	-	Bulk specific gravity
G*	-	Complex modulus
G'	-	Elastic modulus
G''	-	Viscous modulus
G*/sin δ	-	Rutting tarameter for Asphalt Binder
G*sin δ	-	Fatigue Parameter for Asphalt Binder
HAPs	-	Hazardous Air Pollutions
HMA	-	Hot Mix Asphalt
IDT	-	Indirect Tension Test
ITSR	-	Indirect Tensile Strength Ratio
M_R	-	Resilient modulus
NMAS	-	Nominal Maximum Aggregate Size

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N_2O	-	Nitrous Oxide
OBC	-	Optimum Binder Content
JKR	-	Jabatan Kerja Raya
PAV	-	Pressure Aging Vessel
PG	-	Performance Grade
PI	-	Penetration Index
RAP	-	Reclaimed Asphalt Pavement
RTFO	-	Rolling Thin Film Oven
RV	-	Rotational Viscometer
SEM	-	Scanning Electron Microscope
SGC	-	Superpave Gyratory Compactor
SHRP	-	Strategic Highway Research Program
SO_2	-	Sulfur Oxide
SP	-	Softening point
STA	-	Short Term Aged
TCA	-	Trichloroethane
TCE	-	Trichloroethylene
TSR	-	Tensile Strength Ratio
UTM	-	Universal Testing Machine
Va	-	Air void
VFA	-	Void Filled With Asphalt
VMA	-	Void in Mineral Aggregate
WMA	-	Warm Mix Asphalt

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CHAPTER 1

INTRODUCTION

1.1 Research background

Sustainable in context of the new asphalt industry can be explained through decreasing the energy consumption and emissions process by reducing the mixing temperatures of asphalt mixture production (Huffman, 2001). The using of recycled materials becomes significantly relevent with sustainability environmental friendly production processes. Recycling in pavement industry has been referred as a method by which reclaimed asphalt pavement (RAP) is blended with new aggregate and bitumen or recycling agent to produce hot mix asphalt (HMA). This reclaimed asphalt pavement (RAP) can be obtained from pavement milling process or from a ripping and crushing operation.

Nowadays, production emmison of global warming at asphalt plant give bad impact to the environment. A new approach has been used to overcome this problem in road construction by using warm mix asphalt (WMA). The asphalt plant should developed an energy conservation and envitronmental awareness to minimize the impact of global warming. WMA is the technologies that can be implemented in supporting the green technology by replacing the conventional method.

The WMA technology can reduce production temperatures, binder aging, cracking and minimise oxidative hardening since the mixes are produced closer to the operating temperatures (Goh & You, 2011). This technology is produced at temperature of an approximately 25–30°C less than HMA due to chemical composition changes during the mixing process (D'Angelo, 2008). Furthermore, this technology gives several ways like in terms of environmental and construction. With

all the advantages either for the environment or human such as reduce the fumes, asphalt plant emission and energy consumption, it proves that there are apparent benefits to use WMA (Mazumder *et al.*, 2016).

However some improvement and modification have to be made to enhance the characteristics and strength of WMA. For this reason, many researchers have conducted numerous studies to establish new additive materials that can be incorporated into the mixture, mainly by introducing WMA additive into the mixture. On the other hand, there are numerous WMA additives and processes exist in the market. These additives include foaming, organic and chemical additives.. Energy savings and emissions reductions are advantages to environmental with the use of WMA. According to Prowell & Hurley (2007), WMA can reduce fuel consumption by as much as 10–35%, fuel usage decreases 3% for each 6°C drops in mixing temperature. European and Canadian researchers have determined that a 15–70% reduction in sulfur oxide, nitrogen oxide, carbon dioxide and volatile organic compounds emissions are generally realized with the use of WMA (D'Angelo, 2008).

Previous studies by Du and Cross (2007) stated that combination reclaimed asphalt pavement (RAP) and warm mix asphalt (WMA) have become the alternative methods for enhancing sustainability in the asphalt industry. This sustainable alternative by recycling method resulting reduction in consuming natural resources and energy. Additionally, recycling has become one of the most popular pavement rehabilitation alternatives compared to other rehabilitation methods. Recycling becomes one of popular rehabilitation techniques based on field and laboratory data supported with continuous performance data. Several studies have found that the factors influencing rehabilitation technique are economic consideration, energy conservation, environmental effects and engineering consideration.

Most of the paved roads in Malaysia are flexible pavement that consist typically of bituminous surfacing, granular road base, drainage sub base and the formation subgrade. It can be said that, the deteriorated wearing course disposed a large volumes in the form of milling waste every 3 to 5 years. Based on that large volume disposal, no initiatives were taken by road contractors to utilise RAP in construction or rehabilitation of highway and roads. Malaysia government should make it mandatory for the road contractor rather than optional to use RAP in

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awarding contracts so that it will help in reducing abundance of reusable asphalt pavement material stockpiled in empty fields or by roadsides and subsequently, lower the cost of building new highway and roads (Ahmad *et al*., 2014).

In terms of construction, the modification of asphalt binder with WMA additives gives better viable of the mixture and compaction process. Permanent deformation is one of major issues in asphalt pavement. This pavement distress occuring in both asphalt layers and unbound layers. However, potential disadvantages of WMA include increased in rutting, moisture sensitivity, and a lack of long-term field performance results. In the case of the chemical and foaming groups, mixture stiffness may be reduced such that rutting resistance can be problematic (Prowell & Hurley, 2007). In contrast, organic additives may increase stiffness where pavement cracking potential increases.

This study used Advera® from foaming group of WMA additive, which was added into mixture incorporated reclaimed asphalt pavement (RAP) materials. RAP, a by-product from milling process of the pavements is opted as the replacement for aggregates since it is mostly disposed as pavements waste in road rehabilitations. Its reutilization has the potential to create sustainable and productive materials. Another reason that Advera® WMA additive has been chosen because of its attested efficiency in reducing asphalt production temperature. The performance of Advera® WMA mixture incorporated with RAP were evaluated from an engineering perspective. This study was conducted extensively on laboratory experiments to develop and encourage innovative usage of such sustainable of pavement recycling material in the road industry.

1.2 Problem statement

Global warming can be defined as the current increase in temperature of the earth's surface including land and water as well as its atmosphere. Hansen *et al.,* (2010) found that average temperatures around the world have risen by 0.75°C per year. More than 90% studies show that increment of this temperature is due to the greenhouse gases produced by human activities.

The increment quantity of greenhouse gases produced by human activities in large amounts is one of major causes of global warming. Shakun, Jeremy and Anders (2010) described the greenhouse effect is a process where greenhouse gases trap heat in the atmosphere to keep warm enough to sustain life. As shown in Figure 1.1, greenhouse gases come from carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that are normally trap some of the sun's heat, keeping the planet from freezing.

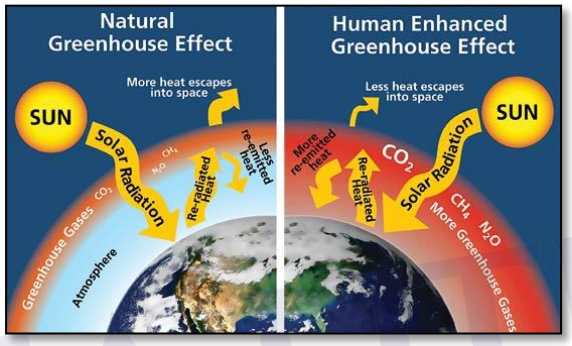

Figure 1.1: Natural greenhouse effect (National Park Service, 2008)

In asphalt mixing plant, drying and mixing HMA process conducted in a rotating drum and heated up to 160 ^{o}C. At this elevated temperature, bitumen-aggregate coating increased, thus improved mix workability during paving operations. Furthermore, high temperature mixing in less than 60 seconds eliminates moisture trapped within the mixes (Haeron and Diefender, 2008; Myers *et al*., 2000).

However, continuous heating at elevated temperature is not sustainable economically and bad for the environment issues. The workers easily exposed with hazardous chemical emissions and greenhouse gasses during mixing. Polycyclic aromatic hydrocarbon and fume exposure become serious concern for long term in asphalt industries. At this point, the rising awareness in greenhouse gasses and global warming must be taken to the next level by taking necessary actions to reduce the effects.

According to Tran, Taylor and Willis (2012) studies reported that production of WMA with various additives at lower mixing and compaction temperature resulting in incomplete drying of the aggregate. The adequate asphaltic layer is one of the requirement in road pavement construction in order to provide a stiff, durable

and permeable layer. The stiff and durable layer prevents undue deformation subjected to the traffic loading. Meanwhile, impermeable asphalt layer acts to prevent water from surface reaching to bottom of pavement structure thus weakening the layers.

Constructions of asphaltic concrete in Malaysia has brought with the problem of the extensive quality control even though these materials are produced complied with the specification. In more cases, this happen due to high traffic stresses at certain areas such as main junctions and climbing zones resulting rapid permanent deformation along the wheel paths. For example, rutting is one type of deformations, which create water ponding when raining and subsequently increase water infiltration into the pavement resulting further weaken to the road structure and pose danger to road users (Shanbara, *et al.,* 2018). As mentioned by Chaturabong and Bahia (2017), rutting distress divided in two types namely asphalt mix rutting occurred on surface pavement and subgrade rutting due to failure pavement of structure. Resurfacing of this wearing course needs large good quality of aggregates from quarry to replace the pavement layer with current combination of WMA and moderate to high percentages of RAP has not been studied in great detail.

Therefore, this study addressed further physical and chemical properties investigations of modified binder with Advera® in terms of aging, viscosity and morphological characteristics. Performance of Advera® warm mix asphalt containing RAP critically conducted to evaluate the optimum percentages of Advera® and RAP through resilient modulus, dynamic creep and moisture susceptibility test. The coupling of WMA and RAP will improve pavement performance and better environmental friendly maintenance from a hypothetical standpoint. However, some modifications on the raw materials including the additive are needed to improve their characteristics and enhance their engineering properties. There are two main research questions in this study:

i. Is Advera® modified binder susceptible to stiffness and rut due to aging using Superpave™ binder tests.
ii. Can Advera® WMA additives incorporating RAP perform well at lower temperature.

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1.3 Research aim and objectives

This study aims to evaluate the performance of Advera® warm mix asphalt incorporating reclaimed asphalt pavement materials. To achieve the above goal, the following specific objectives are outlined as follows:

(i) to investigate the RAP, aggregate and binder materials characteristic and variability with respect of binder content and aggregate gradation.
(ii) to assess the rheological properties and chemical characteristic of asphalt binder prepared with varying percentage of Advera® additive content at various test temperatures.
(iii) to conduct a comparative study on effect of Advera® mixture to the resilient modulus, rutting and moisture susceptibility at warm mix temperature.
(iv) to develop regression models between rheological Advera binder and mixture performance incorporating RAP with establishment of blending and strength chart

1.4 Research scopes

The scope of this study was to establish the WMA mixture incorporating RAP according to Superpave™ mixes design method. Experimental works were conducted to achieve the objectives of the study. The testing methods and work procedures were specified according to the American Society for Testing and Materials (ASTM), American Association of State Highway and Transportation Officials (AASHTO), British Standard (BS) and Malaysian Standard (MS).

A comprehensive literature review of WMA and RAP asphalt concrete was completed to evaluate the primary benefits and distresses found with each material. From the literature review findings, Advera® additive was selected for this research. Advera® was chosen due to its ability in reducing the mixture production temperature approximately 20-30^{O}C without change the design of asphalt mixture. Four (4) series of mix portions with 4%, 5%, 6% and 7% Advera® by total weight of the asphalt binder were blended with asphalt binder PG 64. In addition, RAP material was

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